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TECHNICAL NOTE

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INCIPIENT- AND DEVELOPED-SPIN AND RECOVERY CHARACTERISTICS OF A MODERN HIGH-SPEED FIGHTER DESIGN WITH LOW ASPECT RATIO AS DETERMINED FROM DYNAMIC-MODEL TESTS

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INCIPIENT- AND DEVELOPED-SPIN AND RECOVERY CHARACTERISTICS OF A MODERN HIGH-SPEED FIGHTER DESIGN WITH LOW ASPECT RATIO AS DETERMINED FROM DYNAMIC-MODEL TESTS

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SUMMARY

Incipient- and developed-spin and recovery characteristics of a modern high-speed fighter design with low aspect ratio have been investigated by means of dynamic model tests. A 1/7-scale radio-controlled model was tested by means of drop tests from a helicopter. Several 1/25-scale models with various configuration changes were tested in the Langley 20-foot free-spinning tunnel.

Model results indicated that generally it would be difficult to obtain a developed spin with a corresponding airplane and that either the airplane would recover of its own accord from any poststall motion or the poststall motion could be readily terminated by proper control technique. On occasion, however, the results indicated that if a poststall motion were allowed to continue, a fully developed spin might be obtainable from which recovery could range from rapid to no recovery at all, even when optimum control technique was used. Satisfactory recoveries could be obtained with a proper-size tail parachute or strake, application of pitching-, rolling-, or yawing-moment rockets, or sufficient differential deflection of the horizontal tail.

INTRODUCTION

An investigation was made to determine the incipient- and developed-spin and recovery characteristics of a modern high-speed fighter airplane with low aspect ratio by tests of dynamic models. Several 1/25-scale models with various configuration changes were tested in the Langley 20-foot free-spinning tunnel and a 1/7-scale model of one of the configurations was used for free-flying radio-controlled tests. This report presents the pertinent results of these dynamic-model tests which were made to determine the following:

(1) Probability of the airplane's entering a developed spin

(2) Effects of engine thrust application on the recovery from a developed spin

(3) Effects of flaps and of leading-edge droop

(4) Effects of strakes located on the nose of the fuselage

(5) Size of emergency tail parachute required for recovery from a developed spin by parachute action alone

(6) Effects of the application of reaction controls producing pitching, rolling, or yawing moments to recover from a spin

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(7) Effects of differential operation of the horizontal tail to produce a rolling moment on the recovery from a spin

(8) Effects of various center-of-gravity positions

(9) Effects of changes in moments of inertia

(10) Effects of the vertical location of the horizontal tail

(11) Effects of various control movements on recovery

(12) Effects of configuration changes

SYMBOLS

b	wing span, ft
S	wing area, sq ft
$\bar{c}$	mean aerodynamic chord, ft
$x/\bar{c}$	ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord
$z/\bar{c}$	ratio of distance between center of gravity and fuselage reference line to mean aerodynamic chord (positive when center of gravity is below line)
m	mass of airplane, slugs
I_X, I_Y, I_Z	moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2

$\frac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\frac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

X,Y,Z coordinate axes

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ρ air density, slugs/cu ft

μ relative density of airplane, $m/\rho Sb$

α angle between fuselage reference line and vertical (approximately equal to absolute value of angle of attack in plane of symmetry), deg

β angle of sideslip at nose boom 21 inches from nose of model, deg

ϕ angle between span axis and horizontal, deg

V full-scale true rate of descent, ft/sec

q dynamic pressure, $\frac{1}{2}\rho V^2$

Ω full-scale angular velocity about spin axis, rps

ψ_e azimuth angle, deg

δ_h deflection of horizontal tail, positive with trailing edge down, deg

δ_a deflection of right aileron, positive with trailing edge down, deg

δ_r deflection of rudder, positive with trailing edge left, deg

MODELS

The 1/25- and 1/7-scale models were constructed and prepared for testing by the Langley Research Center of the National Aeronautics and

Space Administration. A three-view drawing showing design 1 and design 2 of the 1/25-scale models is presented in figure 1. The 1/7-scale model is of design 2. The dimensions and locations of the various strakes are shown in figure 2. The various locations of the horizontal tail which were tested are shown in figure 3. A photograph of the 1/25-scale model (design 1) is presented in figure 4. Full-scale dimensional characteristics of the design 1 airplane are presented in table I, and the mass characteristics for representative loadings of the airplanes and for the loadings tested on the models are presented in table II.

The models, as ballasted, were dynamically similar to the airplane at an altitude of 20,000 feet for the spin-tunnel models and 27,000 feet for the radio-controlled model.

The control surfaces, rockets, and parachutes on all models were operated by remote control. Sufficient torque was exerted on the controls to move them fully and rapidly, except for the horizontal tail on the radio-controlled model, which was moved slowly.

The following normal full control deflections (measured perpendicular to the hinge lines) were used for all models during the test program:

Rudder deflection, deg	25 right, 25 left
All-movable horizontal-tail deflection, deg	Trailing edge 17 up, 5 down
Aileron deflection, deg	15 up, 15 down
Flap deflection (leading- and trailing-edge flaps), deg	15 down

TESTING TECHNIQUES

The operation of the Langley 20-foot free-spinning tunnel is similar to that described in reference 1 for the Langley 15-foot free-spinning tunnel except that the model-launching technique is different. With controls set in the desired position, a model is launched by hand with rotation into the vertically rising airstream. After a number of turns in the established spin, a recovery attempt is made by moving one or more of the controls by means of a remote-control mechanism. After recovery, the model dives into a safety net. The angle of attack, angle of roll, rate of rotation, and airspeed are obtained from motion pictures taken during the tests.

The radio-control testing technique is similar to that described in reference 2. The model, which is nonpowered, is released from a

helicopter either into forward gliding flight at an altitude of 3,000 feet and an airspeed just below the stalling speed of the model or by prerotating the model and launching it from a hovering helicopter into a spinning attitude. The model is controlled from the ground by means of a radio link and is maneuvered in various ways in an attempt to force it into a spin. At approximately 1,000 feet a large parachute is deployed which lowers the model to the ground. The tests are photographed with motion-picture cameras on the ground, in the helicopter, and in the model. Time histories of angles of attack and sideslip at the nose boom, model azimuth angle, and control positions are obtained from these films.

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PRECISION

The results determined from the model tests are believed to be accurate within the following limits:

Radio-controlled model:	
α, deg	± 2
β, deg	± 5
Ω, percent	± 2
Spin-tunnel models:	
α, deg	± 1
ϕ, deg	± 1
V, percent	± 5
Ω, percent	± 2
Turns for recovery (from movie film)	$\pm 1/4$
Turns for recovery (visually)	$\pm 1/2$

The limits for the spin-tunnel models may be exceeded for certain spins in which it is difficult to control the model in the tunnel because of the high rate of descent or because of the wandering or oscillatory nature of the spin.

The accuracy of measuring the weight, mass distribution, and control settings of the radio-controlled and spin-tunnel models is believed to be within the following limits:

Weight, percent	± 1
Center-of-gravity location, percent $\bar{c}$	± 1
Moments of inertia, percent	± 5
Control settings, deg	± 1

VARIATIONS IN MODEL MASS CHARACTERISTICS

Because it is impracticable to ballast models exactly and because of inadvertent damage to models during tests, the measured weight and mass distribution of the test models varied from the true scaled-down values within the following limits:

Radio-controlled model:
- Weight, percent . . . . 1 low to 0
- Center-of-gravity location, percent $\bar{c}$ . . . . 1 forward to 0
- Moments of inertia:
  - I_X, percent . . . . 25 high to 30 high
  - I_Y, percent . . . . 1 low to 0
  - I_Z, percent . . . . 0 to 4 high

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Spin-tunnel models:
- Weight, percent . . . . 1 low to 2 high
- Center-of-gravity location (horizontally), percent $\bar{c}$ 0
- Moments of inertia:
  - I_X, percent . . . . 5 high to 35 high
  - I_Y, percent . . . . 2 low to 8 high
  - I_Z, percent . . . . 3 low to 7 high

RESULTS AND DISCUSSION

Spin-Tunnel Results

The investigation yielded generally similar results for all versions of the design. Typical results from erect spins are presented in chart 1. Results not presented in chart form indicated that no developed inverted spins could be obtained. Table III shows the effects of strakes, differential operation of the horizontal tail, and the vertical location of the horizontal tail. The results of engine thrust and of rocket reaction controls used to apply pitching, yawing, and rolling moments are presented in table IV. The results of spin-recovery parachute tests are presented in table V. The effects of center-of-gravity shift and mass changes are shown in table VI.

Even though the model was launched with forced spin rotation, developed erect spins were difficult to obtain. When obtained, recovery by optimum control technique, that is, rudder against and ailerons with the spin (stick right in a right spin) and horizontal-tail trailing edge full up, varied from rapid to no recovery. The spins and recoveries with the

leading- and/or trailing-edge flaps deflected were not appreciably different from the results obtained for the clean condition. However, the model was slightly more prone to spin when all flaps were down than in the clean condition. Lowering the position of the horizontal tail tended to increase the spin rate of rotation. Recoveries from these spins ranged from satisfactory to unsatisfactory.

If developed inverted spins, though not obtained on the models, are obtained on the airplane, recoveries should be possible by neutralizing all controls.

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Consistently satisfactory recoveries from erect spins could be obtained in any of the following ways: by using a 19.8-foot-diameter tail parachute with a 40-foot towline, by using strake 4, by applying 9,800 foot-pounds of rolling moment (with spin), by applying 33,000 foot-pounds of nose-down pitching moment combined with 19,000 foot-pounds of antispin yawing moment, or by using $\pm 50^\circ$ of differential horizontal-tail movement to with the spin.

Radio-Control Results

Data from a developed right spin obtained by abruptly stalling the model from a straight flight path are presented in figure 5 in the form of time histories of the angle of attack and sideslip at the nose boom, control positions, and model azimuth angle. The time scale has been corrected to correspond to full scale. The spin did not change appreciably after the first turn; thus, if the airplane should spin at all, the spin may develop very rapidly. The rate of rotation remained fairly constant at 0.19 turn per second (full-scale); therefore, most of the oscillations in β were rolling oscillations. This spin agrees reasonably well with those obtained on the 1/25-scale models in the spin tunnel. Of six attempts to enter a spin by stalling the model from straight flight, only one produced a spin. All other attempts ended in near-vertical rolling dives. Furthermore, 11 attempts to spin the model by prerotating it and releasing it in a spinning attitude from a hovering helicopter produced only two spins. The data obtained from these spins are essentially the same as those obtained from a normal entry. The other nine attempts ended in near-vertical rolling dives.

The test results from the spin-tunnel and radio-controlled models showed no Reynolds number effect, and in general the results for both models indicated that it will be difficult to obtain a developed spin with this design. However, an occasional developed spin was obtained with the models, and recovery by optimum control technique was unsatisfactory. It is therefore considered desirable that spins be terminated early in the incipient phase. Generally a poststall motion ensued and either the model recovered of its own accord or the motion could be

readily terminated by proper control technique. The optimum control technique for recovery from the incipient phase of the spin or a post-stall motion would be rudder full against, ailerons full with (stick right in a right spin), and horizontal-tail trailing edge full up.

Comparison of Model and Airplane Results

The model tests predicted quite well what the airplane would do, the most significant factor being the difficulty of obtaining a developed spin. The time histories of α and β oscillations in a spin L
are very similar for the model and the airplane, although the average 1
value of α was a little lower for the airplane than for the model. 6
The airplane did not have any unsatisfactory recoveries in its test 6
program. However, the available time histories of motions of the air- 2
plane which were termed spins do not include many turns before controls were moved and do not appear to represent developed spins. Therefore the recoveries from these motions, in some instances, were not due to the control manipulations but occurred in spite of the controls applied.

CONCLUSIONS

Incipient- and developed-spin and recovery characteristics of a modern high-speed fighter design with low aspect ratio have been investigated by means of dynamic-model tests. The results of the investigation indicate the following conclusions:

1. It will be difficult to obtain a fully developed spin with the airplane.

2. If a developed spin should occur, recoveries therefrom may be satisfactory or unsatisfactory, even though the optimum control technique is used; that is, rudder full against, ailerons full with, and horizontal-tail trailing edge full up.

3. There were essentially no differences in the results obtained from the various versions of the design.

4. Satisfactory spin recoveries can be obtained by means of the following:

(a) A tail parachute of sufficient size

(b) Strakes of proper size and location on the nose of the airplane

(c) Application of pitching, rolling, or yawing moments of sufficient magnitude through use of rocket reaction controls

(d) Sufficient differential deflection of the horizontal tail

5. The use of wing trailing-edge flaps and leading-edge droop has little effect on recovery from a developed spin.

6. It will be difficult or impossible to obtain a developed inverted spin with this airplane.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., July 5, 1961.

REFERENCES

1. Zimmerman, C. H.: Preliminary Tests in the N.A.C.A Free-Spinning Wind Tunnel. NACA Rep. 557, 1936.

2. Libbey, Charles E., and Burk, Sanger M., Jr.: A Technique Utilizing Free-Flying Radio-Controlled Models to Study the Incipient- and Developed-Spin Characteristics of Airplanes. NASA MEMO 2-6-59L, 1959.

TABLE I.- FULL-SCALE DIMENSIONAL CHARACTERISTICS OF THE

DESIGN 1 AIRPLANE

Overall length, ft	49.17
Wing:	
Span, ft	21.83
Area, sq ft	191.00
Airfoil section	Modified biconvex 3.4 percent thick
Mean aerodynamic chord, in.	112
Longitudinal distance from wing apex to leading edge of mean aerodynamic chord, in.	27.5
Root chord, in.	152
Tip chord, in.	58
Incidence, deg	0
Dihedral, deg	-10
Taper ratio	0.382
Aspect ratio	2.5
Sweepback of 25-percent-chord line, deg	18
Aileron area, total, sq ft	10.06
Trailing-edge flaps:	
Area, total, sq ft	24.3
Maximum flap-down angle, deg	30
Leading-edge flaps:	
Area, total, sq ft	16.00
Maximum flap-down angle, deg	30
Horizontal tail:	
Area, total, sq ft	47.5
Area, movable, sq ft	47.0
Sweepback of 25-percent-chord line, deg	9
Airfoil section:	
Root	Modified biconvex 5 percent thick
Tip	Modified biconvex 2.25 percent thick
Root chord, in.	73
Tip chord, in.	22.726
Vertical tail:	
Area, total, sq ft	34.7
Area, rudder, sq ft	4.4
Sweepback of 25-percent-chord line, deg	35
Airfoil section:	
Root	Modified biconvex 4.25 percent thick
Tip	Modified biconvex 5 percent thick
Root chord, in.	112.5
Tip chord, in.	43
Tail-damping ratio	0.2762
Unshielded-rudder volume coefficient	0.0378
Tail-damping power factor	0.01044

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TABLE II.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR REPRESENTATIVE LOADINGS OF THE DESIGN 1 AND DESIGN 2 AIRPLANES AND FOR LOADINGS TESTED ON THE 1/25-SCALE MODELS

[Model values converted to corresponding full-scale values]

No.	Loading	Weight, lb	Center-of-gravity location		Relative density of airplane, μ		Moments of inertia about c.g., slug-ft^2			Mass parameters		
			$x/\bar{c}$	$z/\bar{c}$	At sea level	At 20,000 ft	I_X	I_Y	I_Z	$\frac{I_X - I_Y}{mb^2}$	$\frac{I_Y - I_Z}{mb^2}$	$\frac{I_Z - I_X}{mb^2}$
	Design 1 airplane											
1	Normal take-off	16,151	0.10	-0.010	50.6	95.0	3,174	41,615	42,633	$-1,607 \times 10^{-4}$	-43×10^{-4}	$1,650 \times 10^{-4}$
	Design 2 airplane											
2	Combat gross weight	15,200	0.07	-0.021	47.60	89.34	3,409	56,655	57,630	$-2,367 \times 10^{-4}$	-43×10^{-4}	$2,410 \times 10^{-4}$
	Design 1 model											
1	Normal take-off	16,455	0.096	-0.020	50.97	96.2	2,815	43,173	43,581	$-1,657 \times 10^{-4}$	-17×10^{-4}	$1,674 \times 10^{-4}$
3	Overload gross (wing-tip tanks on and full)	18,440	0.12	-0.004	57.8	108.5	12,857	40,999	50,200	$-1,031 \times 10^{-4}$	-337×10^{-4}	$1,368 \times 10^{-4}$
4	Forward c.g. position	16,183	0	-0.021	50.71	95.2	3,599	40,655	41,106	$-1,546 \times 10^{-4}$	-19×10^{-4}	$1,565 \times 10^{-4}$
	Design 2 model											
2	Combat gross weight	15,541	0.08	-0.035	48.71	91.43	4,657	56,940	57,284	$-2,271 \times 10^{-4}$	-15×10^{-4}	$2,286 \times 10^{-4}$
5	Forward c.g. position	15,688	0	-0.040	49.12	92.18	4,084	57,623	58,666	$-2,284 \times 10^{-4}$	-44×10^{-4}	$2,332 \times 10^{-4}$
6	Rearward c.g. position	15,577	0.17	-0.039	48.81	91.61	3,200	46,174	46,649	$-1,864 \times 10^{-4}$	-21×10^{-4}	$1,884 \times 10^{-4}$
7	Forward c.g. position	15,027	0.10$\bar{c}$ forward of L.E. of $\bar{c}$	-0.048	47.10	88.40	3,384	38,706	38,948	$-1,588 \times 10^{-4}$	-11×10^{-4}	$1,599 \times 10^{-4}$

TABLE III.- REPRESENTATIVE EFFECTS ON THE SPIN AND RECOVERY CHARACTERISTICS OF STRAKES, DIFFERENTIAL HORIZONTAL-TAIL MOVEMENT, AND VERTICAL LOCATION OF THE HORIZONTAL TAIL TESTED ON THE MODELS

[Recovery attempted from and developed-spin data presented for rudder full with spins; right erect spins; model values converted to corresponding full-scale values]

Spin no.	Model loading no. (see table II)	Strake no. (see fig. 2)	Horizontal-tail position no. (see fig. 3)	Control setting for spin: Ailerons (a)	Control setting for spin: Horizontal tail as - Elevator	Control setting for spin: Horizontal tail as - Ailerons	Control setting for spin: Flaps as ailerons (a)	V, fps	Ω, rps	α, deg (b)	φ, deg (b, c)	Control movement for recovery (a): Ailerons	Control movement for recovery (a): Horizontal tail as aileron	Control movement for recovery (a): Flaps as ailerons	Control movement for recovery (a): Rudder	Control movement for recovery (a): Strake no.	Turns for recovery	Remarks
Strakes (design 2)																		
1	5	1 (both sides)	---	0	17° Up	---	-----	---	----	---	----	-----	-----	-----	-----	---	--------------	No spin; trims flat
2	5	2 (both sides)	---	0	17° Up	---	-----	---	----	---	----	-----	-----	-----	-----	---	--------------	No spin; trims flat
3	2	[d]5	---	10° A	0	---	-----	254	----	---	----	10° W	-----	-----	17° A	5	1/4, 1/2	For recovery the strake was rapidly extended on inboard side only
4	2	[d]4	---	10° A	0	---	-----	254	----	---	----	10° W	-----	-----	17° A	4	1/4, 1 1/4	For recovery the strake was rapidly extended on inboard side only
5	2	[d]5	---	15° A	4° Down	---	-----	254	0.16	61 76	14 U 19 D	-----	-----	-----	0°	5	1/4, 1 1/2	For recovery the strake was rapidly extended on inboard side only
6	2	[d]5	---	15° A	4° Down	---	-----	254	0.16	61 76	14 U 19 D	-----	-----	-----	0°	5	[e]	For recovery the strake was rapidly extended on inboard side only
Differential horizontal-tail movement (design 1)																		
7	1	---	---	15° A	17° Up	0	-----	284	0.20	62 72	10 U 8 D	-----	17° W	-----	25° A	---	[e]1/4, [f]1, >10	
8	1	---	---	15° A	17° Up	0	-----	284	0.20	62 72	10 U 8 D	-----	30° W	-----	25° A	---	[e]1, >4	
9	1	---	---	15° A	17° Up	0	-----	284	0.20	62 72	10 U 8 D	-----	40° W	-----	25° A	---	[e]1/2, [e]1/4, 1, >1 1/2	
10	1	---	---	15° A	17° Up	0	-----	284	0.20	62 72	10 U 8 D	-----	50° W	-----	25° A	---	[e]1, [e]1	
11	1	---	---	15° A	17° Up	0	-----	284	0.20	62 72	10 U 8 D	15° W	40° W	-----	25° A	---	[f]1/4, [e]1/4, [e]1, [f]2	
Vertical location of horizontal tail (design 1)																		
12	1	---	1	15° A	10° Up	---	-----	248	0.50	80 90	4 U 10 D	-----	-----	-----	-----	---		Two types of spins; no spin also obtained, where model went into a near-vertical aileron roll
								284	0.21	63 77	15 U 14 D	-----	-----	-----	-----	---		
13	1	---	1	15° W	10° Up	---	-----	256	0.47	80 87	4 U 8 D	-----	-----	-----	-----	---		No spin also obtained; went into a vertical aileron roll
14	1	---	1	45° W	10° Up	---	45° W	---	----	---	----	-----	-----	-----	-----	---		No spin; model went into a rapid vertical aileron roll
15	1	---	2	5° A	10° Up	---	5° A	295	0.26	71 78	25 U 15 D	45° W	-----	45° W	25° A	---	1/4, 1 1/2, >2 1/2	Three types of spins possible; recoveries run only from flattest spin; recovered in a rapid vertical aileron roll
								325	0.15	42 67	12 D 32 D	-----	-----	-----	-----	---		
								275	0.20	45 90	20 U 16 D	-----	-----	-----	-----	---		

[a]A - against, W - with.
[b]Oscillatory spin. Range of values given.
[c]U - inner wing up, D - inner wing down.
[d]Strakes retracted on both sides.
[e]Trimmed flat after spin rotation ceased.
[f]Recovered in a steep aileron roll.

TABLE IV.- REPRESENTATIVE RESULTS OF ROCKET-RECOVERY SPIN TESTS ON THE 1/25-SCALE MODEL OF THE DESIGN 2 AIRPLANE WITH THE ROCKET SIMULATING ENGINE THRUST OR PITCHING, YAWING, AND ROLLING MOMENT

[Model loading 2 (see table II); recovery attempted by firing rockets; right erect spins; clean condition; model values converted to corresponding full-scale values]

Spin no.	Control setting for spin (a)			Moment applied, ft-lb			Engine thrust applied, lb	Approx. firing time, sec	Turns for recovery
	Ailerons	Elevator	Rudder	Pitch	Yaw	Roll			
b1	15° A	4° D	25° W	-------	-------	-----	6,250	----	>4, c∞, >8
2	15° A	17° Up	25° W	-------	-------	-----	8,300	----	$\frac{1}{2}$, c>2, ∞
3	15° A	4° D	25° W	-38,000	-------	-----	-----	5	1, c∞, $\frac{3}{4}$, $\frac{3}{4}$
4	0	17° Up	25° W	-33,000	-19,000	-----	-----	10	$\frac{1}{4}$, $\frac{1}{2}$
5	0	17° Up	25° W	-------	-------	4,900	-----	2.5	$\frac{1}{2}$, $\frac{1}{2}$
6	0	4° D	25° W	-------	-------	4,900	-----	2.5	∞, ∞
7	0	4° D	25° W	-------	-------	4,900	-----	7.5	$1\frac{1}{4}$, 1, $\frac{1}{4}$
8	0	17° Up	25° W	-------	-------	9,800	-----	5.0	d1, d$\frac{1}{2}$

[a] A - against, W - with, D - down.

[b] Leading- and trailing-edge flaps down 15°.

[c] Spin rotation increased while rocket was firing.

[d] Went into a steep rapid roll to the right.

TABLE V.- REPRESENTATIVE RESULTS OF SPIN-RECOVERY TAIL-PARACHUTE TESTS

ON THE 1/25-SCALE MODEL OF THE DESIGN 1 AND DESIGN 2 AIRPLANE

[Recovery attempted by opening parachute; right erect spins; clean condition; model values converted to corresponding full-scale values]

Parachute		Shroud-line length, ft	Towline length, ft	Model loading no. (see table II)	Control setting for spin (b)			Turns for recovery
Diam.,[a] ft	Drag coeff., C_D				Ailerons	Elevator	Rudder	
Design 1								
12.5	0.71	17.0	21.7	1	5° A	17° Up	25° W	$\frac{1}{4}$, $1\frac{1}{2}$, $\frac{1}{2}$, $1\frac{1}{2}$, >4
12.5	0.71	17.0	27.0	1	5° A	17° Up	25° W	$\frac{1}{2}$, $\frac{1}{2}$, 1, $\frac{1}{2}$, $\frac{1}{4}$, $\frac{3}{4}$
12.5	0.71	17.0	40.0	1	5° A	17° Up	25° W	$\frac{1}{4}$, $\frac{1}{4}$, [c]$\frac{1}{4}$, [c]$\frac{1}{2}$, [c]$\frac{1}{2}$, [c]$\frac{1}{2}$
Design 2								
14.7	0.65	22.0	27.0	5	0	17° Up	25° W	$\frac{1}{2}$, ∞, ∞
14.7	0.65	22.0	40.0	5	0	17° Up	25° W	$1\frac{1}{4}$, >6, ∞
19.8	0.65	22.0	19.0	5	0	17° Up	25° W	$\frac{1}{2}$, $\frac{1}{2}$, 1, $\frac{1}{4}$, $\frac{1}{4}$, ∞
19.8	0.65	22.0	27.0	5	0	0	25° W	$\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{4}$, $\frac{1}{2}$
[d]19.8	0.65	26.7	40	2	15°	4° D	25° W	$\frac{1}{2}$, $\frac{1}{2}$, $\frac{1}{2}$, 1, 1, 1

[a]Laid-out-flat diameter.

[b]A - against, W - with, D - down.

[c]After recovery, model rolled rapidly about X body axis in direction of aileron deflection.

[d]Leading- and trailing-edge flaps down 15°.

TABLE VI.- REPRESENTATIVE RESULTS OF THE EFFECT OF CENTER-OF-GRAVITY SHIFT AND MASS CHANGES

[Recovery attempted from and steady-spin data presented for rudder full with spins; right erect spins; clean condition; model values converted to corresponding full-scale values]

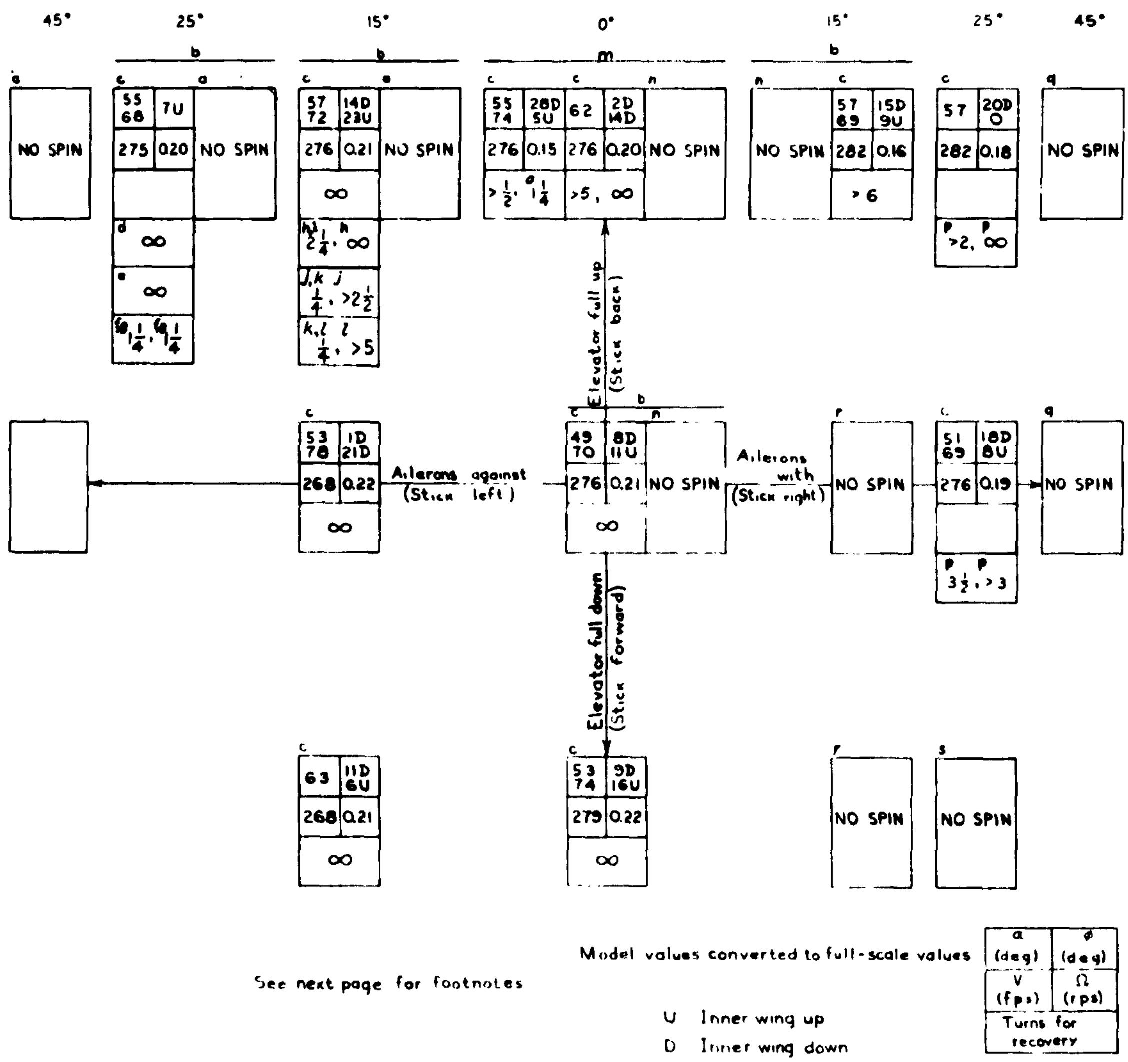
Spin no.	Model loading no. (see table II)	c.g. location, % $\bar{c}$	Control setting for spin		V, fps	Ω, rps	α, deg (b)	ϕ, deg (b,c)	Control movement for recovery (d)		Turns for recovery	Remarks
			Ailerons (a)	Elevator					Ailerons	Rudder		
Design 1												
1	4	0	15° A	17° Up	---	----	---	----	-----	-----	-----	No spin
2	4	0	15° A	0°	315	0.26	52 67	21 U 22 D	15° W	25° A	8, ∞	No spin also obtained
3	4	0	15° A	4° Down	315	0.26	54 67	19 U 30 D	15° W	25° A	$4\frac{1}{2}$, >4	No spin also obtained
Design 2												
4	5	0	15° A	17° Up	254	0.20	55 65	4 U 16 D	15° W	25° A	$\frac{3}{4}$, $1\frac{1}{2}$	No spin also obtained
5	5	0	5° A	11° Up	254	0.18	69	6 U 29 U	10° W	17° A	$\frac{1}{2}$, >3	No spin also obtained
6	5	0	15° A	4° Down	254	0.20	50 66	15 U 9 D	15° W	25° A	1, >4	No spin also obtained
7	6	17	15° A	17° Up	261	0.17 to 0.14	56 83	17 U 16 D	15° W	25° A	$\frac{1}{4}$, >4	No spin also obtained
8	6	17	5° A	11° Up	261	0.17	66 84	19 U 13 D	10° W	17° A	4, ∞	No spin also obtained
9	6	17	15° A	4° Down	254	0.19	54 88	19 U 21 D	15° W	25° A	1, $4\frac{3}{4}$	No spin also obtained

[a] A - against.
[b] Oscillatory spin. Range of values given.
[c] U - inner wing up, D - inner wing down.
[d] A - against, W - with.

CHART 1.- ERECT-SPIN AND RECOVERY CHARACTERISTICS OF

A 1/25-SCALE MODEL OF THE DESIGN 1 AIRPLANE

[Normal take-off loading (loading 2 in table II); recovery attempted by rapid full rudder reversal except as indicated (recovery attempted from, and developed-spin data presented for, rudder full with spins); right erect spins]



See next page for footnotes

Footnotes for Chart 1

[a]Recovers in a vertical aileron roll to pilot's left.

[b]Two conditions possible.

[c]Oscillatory spin. Range of values or average values given.

[d]Recoveries attempted by rudder reversal to full against the spin, elevator to full down, and ailerons from 25° against to 25° with the spin.

[e]Recoveries attempted by rudder reversal to full against the spin, elevator to full down, and ailerons from 25° against to 35° with the spin.

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[f]Recoveries attempted by rudder reversal to full against the spin, elevator to full down, and ailerons from 25° against to 45° with the spin.

[g]Recovered in a glide but started to dive as the model hit the net.

[h]Recoveries attempted by rudder reversal to full against the spin, elevator to full down, and ailerons from 15° against to 15° with the spin.

[i]Dived inverted on recovery.

[j]Recoveries attempted by rudder reversal to full against the spin, elevator to full down, and ailerons from 15° against to 45° with the spin.

[k]Recovers in a flat glide with an angle of attack of approximately 60° or recovers in a vertical aileron roll.

[l]Recoveries attempted by rudder reversal to full against the spin, elevator to full down, and ailerons from 15° against to 60° with the spin.

[m]Three conditions possible.

[n]Ceases rotating and trims at $\alpha \approx 70^\circ$ while gliding and turning to pilot's left.

[o]Recovered in a flat glide with an angle of attack of approximately 60°.

[p]Recoveries attempted by rudder reversal to full against the spin and elevator to full down.

[q]Recovers in a glide.

[r]Recovers in gliding turn to pilot's right.

[s]Recovers in a dive.

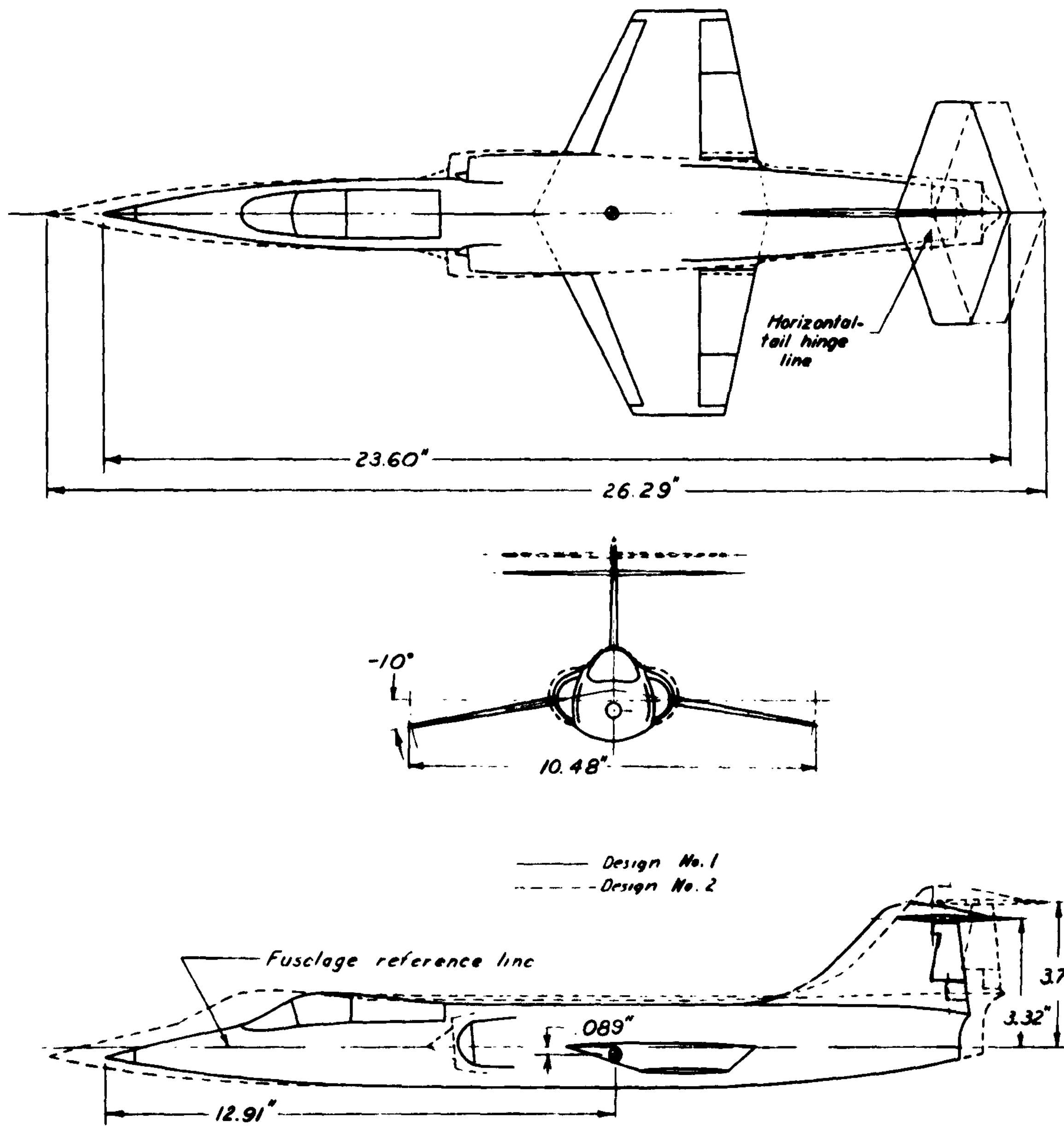

Figure 1.- Three-view drawings of the 1/25-scale models of design 1 and 2 as tested in the Langley 20-foot free-spinning tunnel. Center-of-gravity position shown is for the design 1 normal take-off loading.

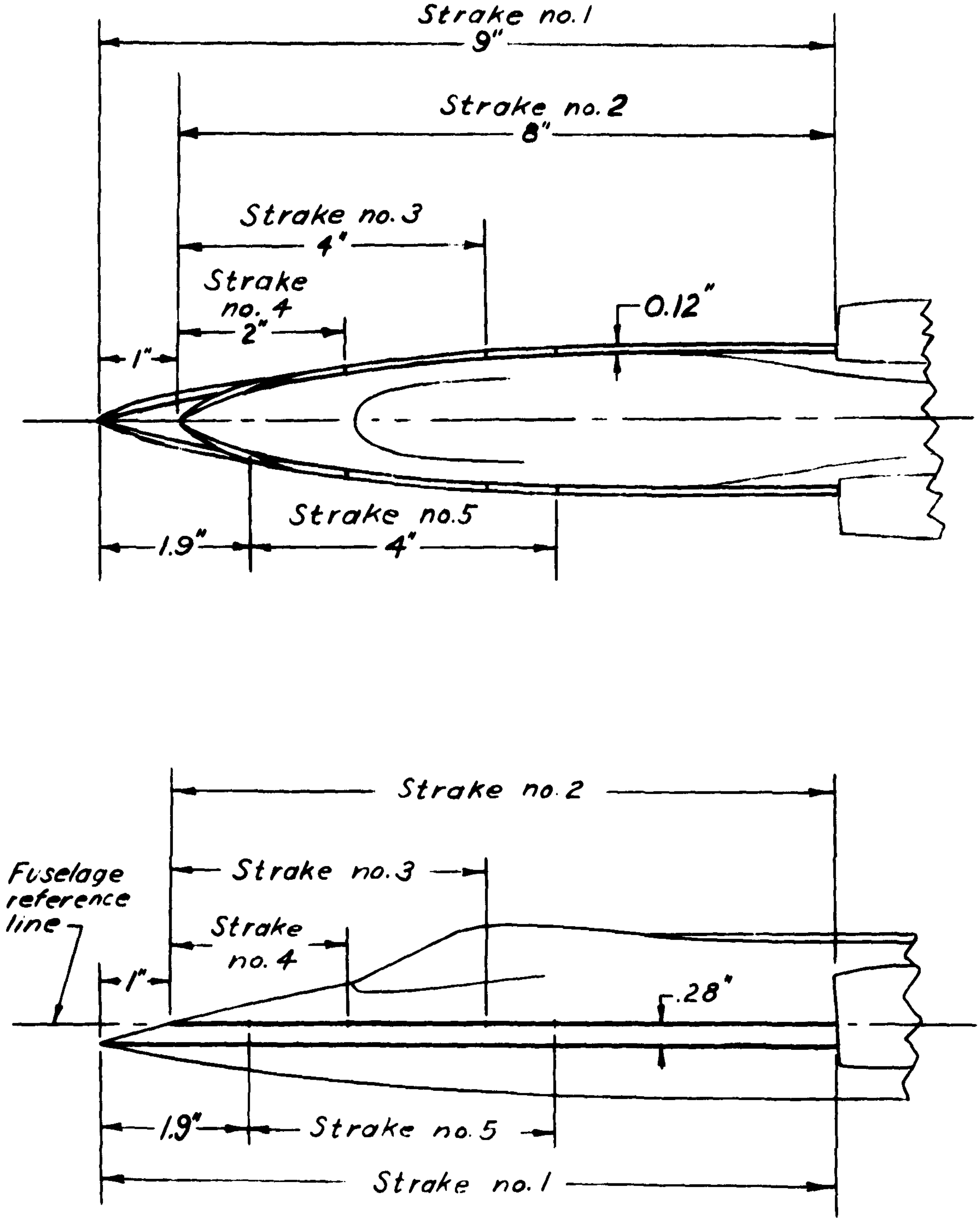

Figure 2.- The nose of the 1/25-scale model of design 2, showing the positions of the strakes tested.

L-1662

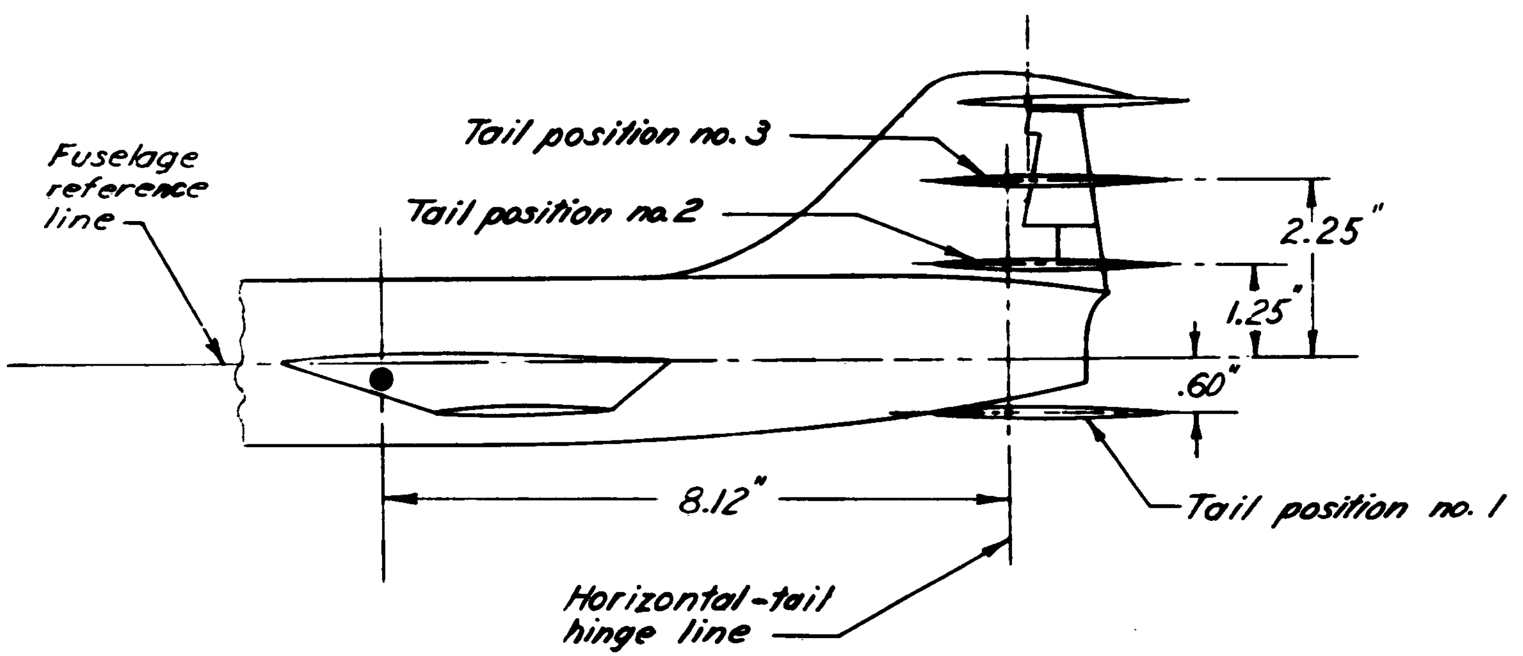

Figure 3.- The tail section of the 1/25-scale model of the design 1 airplane, showing the additional horizontal-tail positions tested. Center-of-gravity position shown is for the normal take-off loading.

L-1057

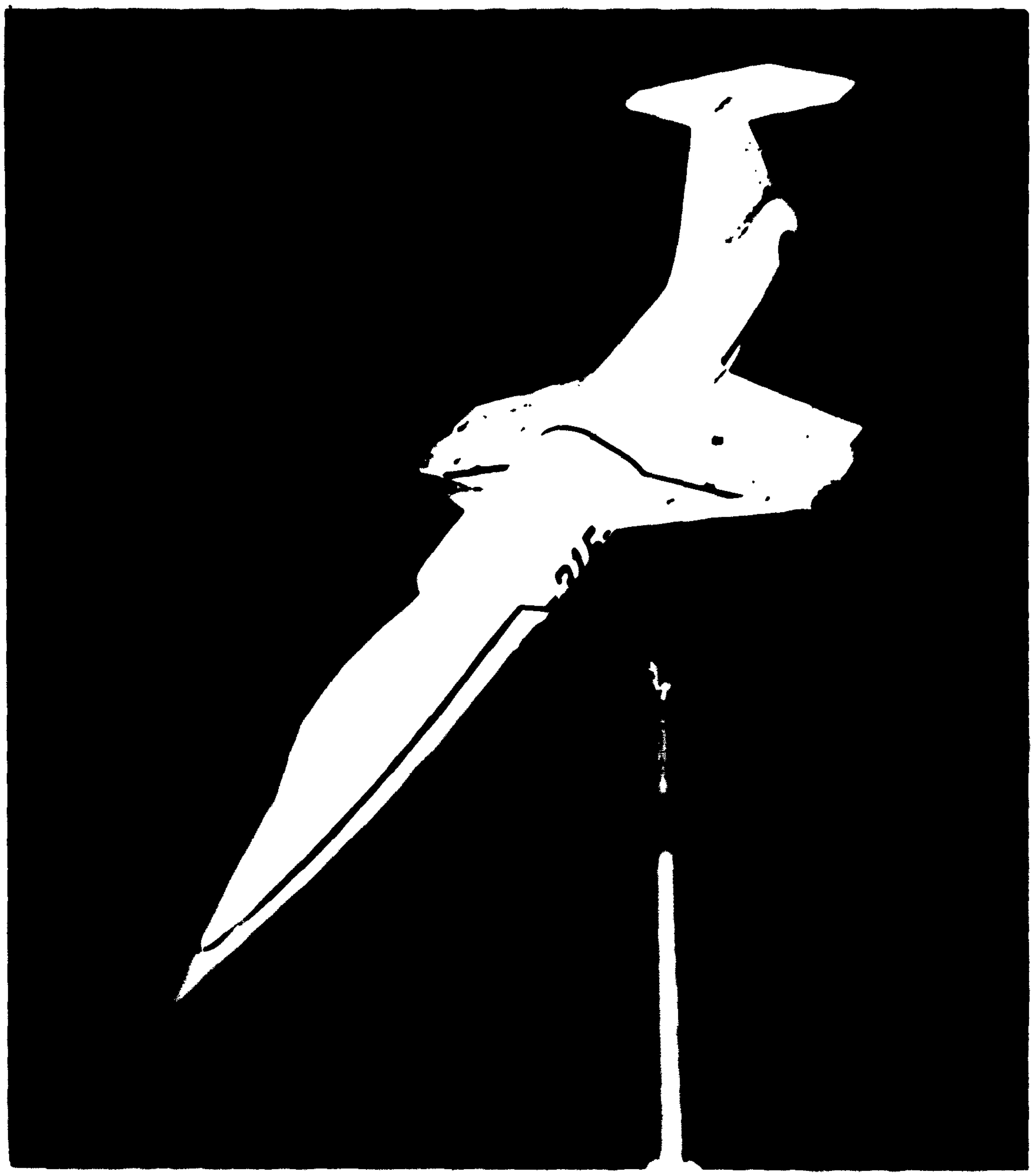

Figure 4.- The 1/25-scale model of design 1. L-83351

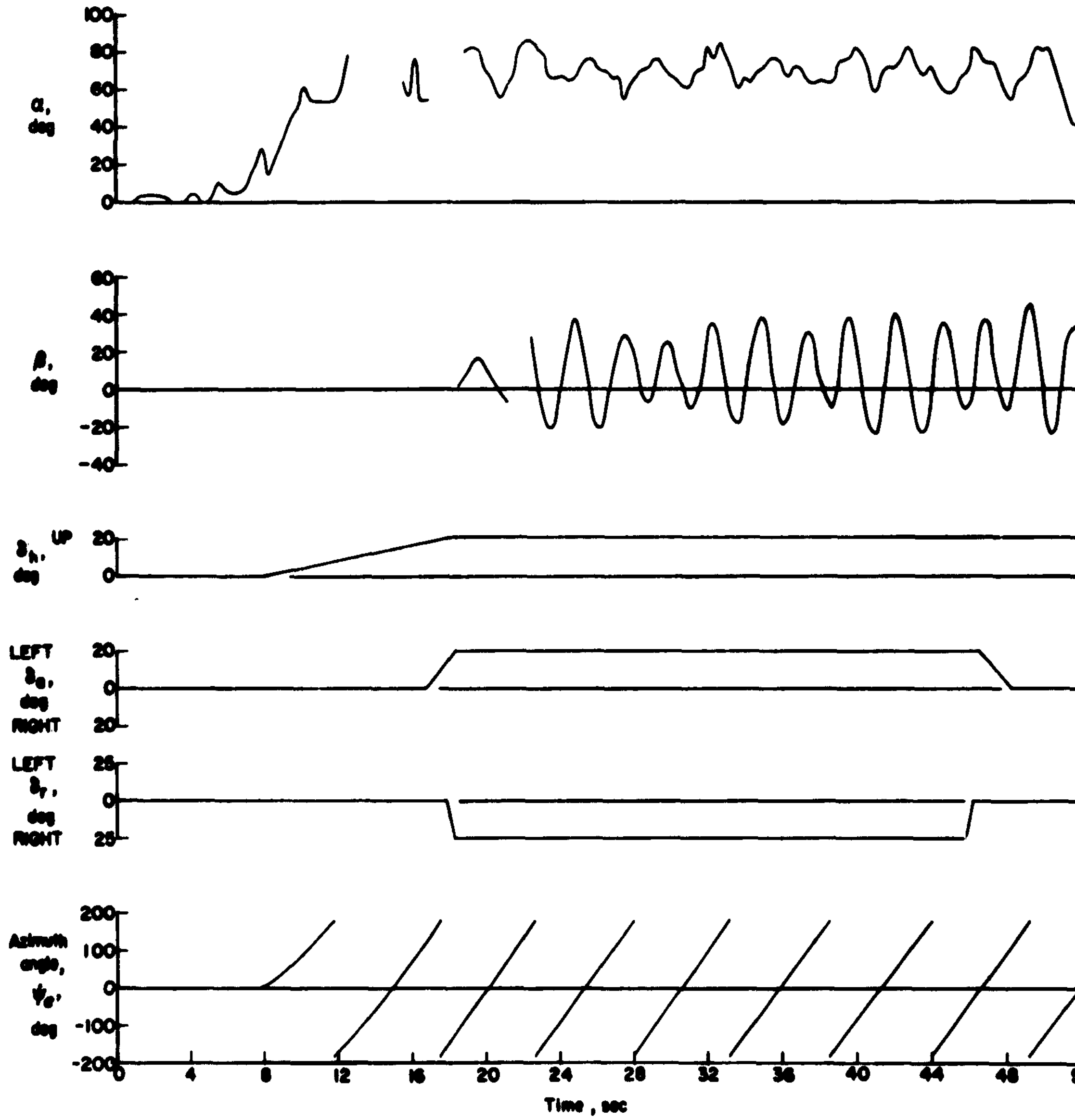

Figure 5.- Time-history results of a spin from radio-controlled model of design 2. Time scale converted to full scale.

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INCIPIENT- AND DEVELOPED-SPIN AND RECOVERY CHARACTERISTICS OF A MODERN HIGH-SPEED FIGHTER DESIGN WITH LOW ASPECT RATIO AS DETERMINED FROM DYNAMIC-MODEL TESTS. Henry A. Lee and Charles E. Libbey. December 1961. 22p. OTS price, $0.75. (NASA TECHNICAL NOTE D-956)

A 1/7-scale radio-controlled model was tested by means of drop tests from a helicopter. Several 1/25-scale models were tested in the Langley 20-foot free-spinning tunnel. Results indicate that fully developed spins were difficult to obtain. However, when they were obtained the recoveries by optimum control technique were unsatisfactory. Satisfactory recoveries could be obtained with a proper-size tail parachute or strake, application of pitching-, rolling-, or yawing-moment rockets, or sufficient differential deflection of the horizontal tail.

Copies obtainable from NASA, Washington

I. Lee, Henry A.
II. Libbey, Charles E.
III. NASA TN D-956

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